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Moderate resolution spectroscopy for the Space Infrared Telescope Facility (SIRTF)

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Abstract

A conceptual design for an infrared spectrometer capable of both low resolution (λ/Δ-λ = 50; 2.5-200 microns) and moderate resolution (1000; 4-200 microns) and moderate resolution (1000; 4-200 microns) has been developed. This facility instrument will permit the spectroscopic study in the infrared of objects ranging from within the solar system to distant galaxies.

The spectroscopic capability provided by this instrument for SIRTF will give astronomers orders of magnitude greater sensitivity for the study of faint objects than had been previously available. The low resolution mode will enable detailed studies of the continuum radiation. The moderate resolution mode of the instrument will permit studies of a wide range of problems, from the infrared spectral signatures of small outer solar system bodies such as Pluto and the satellites of the giant planets, to investigations of more luminous active galaxies and QSOs at substantially greater distances.

A simple design concept has been developed for the spectrometer which supports the science investigation with practical cryogenic engineering. Operational flexibility is preserved with a minimum number of mechanisms. The five modules share a common aperture, and all gratings share a single scan mechanism. High reliability is achieved through use of flight-proven hardware concepts and redundancy. The design controls the heat load into the SIRTF cryogen, with all heat sources other than the detectors operating at 7K and isolated from the 4K cold station. Two-dimensional area detector arrays are used in the 2.5-120μm bands to simultaneously monitor adjacent regions in extended objects and to measure the background near point sources.

Introduction

Through the study of spectral lines and energy distributions, it is possible to gain unique insight into the physical phenomena that characterize our universe. Spectra of distant galaxies revealed the cosmological expansion of the universe and ultimately led to the discovery of quasars. Radial velocity is still the primary characteristic used to determine the distance of extragalactic objects. Many celestial objects are identified almost exclusively through spectral lines, for example, quasars, Seyfert galaxies and interstellar clouds. Spectra have provided the bulk of our knowledge about the chemical composition, excitation state, density and temperature of galactic and extragalactic objects; spectroscopy is an invaluable tool in the study of most astronomical phenomena.

Infrared lines are less effected by extinction and scattering than are optical and UV lines, and because most of their intrinsic emissivities are temperature insensitive, these lines are well suited to the study of many interesting problems. When combined with UV, optical, and radio data, infrared measurements help generate a complete physical picture of an object.

Unfortunately, ground-based infrared spectroscopy is plagued by large backgrounds due to atmospheric and telescope emission and by atmospheric attenuation. SIRTF will remove limiting factors and place infrared spectroscopy on a par with optical work. We have designed a spectrometer for SIRTF which will take advantage of the unique low background environment provided by SIRTF. The spectrometer is designed to be versatile while maintaining simplicity for dependability and ease-of-use. It will cover the $2.5 < \lambda < 200$ μm wavelength range in both low- and high-resolution modes making the instrument applicable to a wide range of problems in astrophysics.

Scientific objectives

The spectrometer will enable the study of a broad class of astrophysical topics, ranging from

(1) The determination of the integrated properties of galaxies (e.g., shift/ luminosity, thermal vs nonthermal mechanisms, large-scale kinematics), to

(2) Studies of the distribution of different properties within individual galaxies (e.g., star formation rates and elemental abundance gradients), to

(3) Problems involving individual objects within a galaxy (e.g., regions of star formation, planetary nebulae), to

(4) Investigations of the outer reaches of our solar system (e.g., the outer planets, coplanets, comets and asteroids).

Below we outline several illustrative examples of the different classes of problems that can be studied using the SIRTF infrared spectrometer.

Emission line fluxes will be measured using the high-resolution mode of the spectrometer. In this mode it will be possible to separate and identify most of the important diagnostic lines needed to probe the physical condition of individual objects such as HII regions, molecular clouds, and planetary nebulae. Many ions are available for determining the excitation state as well as the density structure of these objects. Infrared lines also allow the examination of global properties and hence phenomena such as the clumpiness (density structure) of HII regions. Cloud fragmentation and star formation processes can be examined in this manner by selecting regions with differing dynamical age (rms density or size). Ions such as OI and CII serve as diagnostics of the low-excitation component of the interstellar medium. These lines can be spatially mapped in our galaxy and nearby galaxies to aid in understanding the thermal equilibium of the interstellar medium. Emission from OH, CO, H_2O and H_2 due to molecular shocks will be readily detectable with the spectrometer. These lines will provide insight into the densities, temperatures and physical structure of these shocked regions.

The problem of the chemical evolution of galaxies is an exciting, rich area of study, requiring knowledge of the processes of star formation, stellar evolution, nucleosynthesis, mass loss, and mixing within the interstellar medium. Studies of these processes will contribute directly to our understanding of the problems of normal and starburst galaxy evolution, initial stellar mass functions under different environmental conditions, the hidden mass problem and planet formation. The spectrometer will allow the measurement of abundances and physical conditions in galaxies to well beyond the Virgo cluster. Searches for abundance gradients in nearby galaxies can be performed uninhibited by the temperature and/or extinction effects which often complicate other studies.

Studies of stellar and dust continuum emission under zodiacal and galactic background limited conditions will be performed using the low-resolution mode of the spectrometer. Because solid-state emission and absorption features, such as the 10-micron silicate feature and the various "unidentified" infrared features, can be unambiguously recognized, this mode will provide opportunities for examining dust properties, dust content and stellar content in many galactic and extragalactic objects. Low-resolution spectroscopy will be essential in the determination of the redshifts of objects with moderate to high redshifts which have no optical identification. The low-resolution spectrometer will provide complementary observations to aid in the identification of sources detected with the other SIRTF instruments which may have infrared to visible luminosities even greater than those detected by IRAS (i.e., > 1000:1).

Spectrometer description

The spectrometer was designed to provide the resolution and sensitivity required to accomplish the scientific programs outlined above. One of the primary design goals was to develop a very general instrument with the flexibility needed to support the wide variety of new scientific programs likely to appear in the next few years. Additional design considerations include the desire to maximize the use of developed technologies and maximize the instrumental complexity while incorporating the very best detectors available. The current conceptual design employs five separate spectrometer modules. A schematic is shown in Figure 1. The light from the main telescope encounters filter and aperture wheels before being steered into one of the five modules by the beam diverter mirror. A Cassigrain collimator delivers the light to the dispersing element, in this case one of the two gratings that are mounted back-to-back on the same shaft. (A 180-degree rotation of the grating shaft brings the other grating into use.) Following the disperser a camera mirror reimages the entrance aperture onto the detector array.

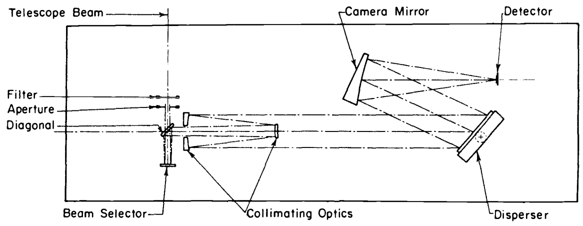

Figure 1. A schematic diagram of the optical configuration for one of five of the spectrometers modules. See text for details.

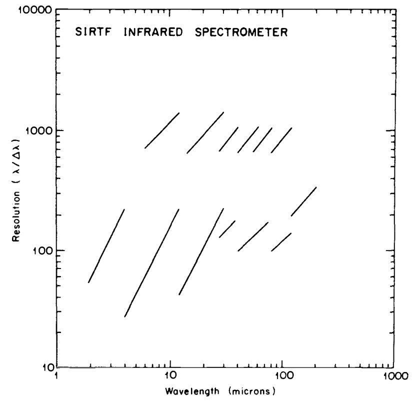

Figure 2. Resolution of SIRTF spectrometer as a function of wavelength. Each curve represents a given grating (or prism) and filter combination.

Each of the five modules has separate collimating, dispersing and camera optics as well as separate detector arrays. However, they do share a common grating shaft. Although this provides a serious failure mode, it eliminates the need for five separate grating drives. The drive for the single grating shaft has two redundant torque motors and shaft encoders. Any motor-encoder pair can be used control the shaft orientation. This provides the necessary redundancy to insure reliable operation for the long lifetime needed.

Figure 2 shows the spectrometer's resolution as a function of wavelength for the various modules in the current concept. For line observations, a resolution of approximately 1,000 is provided from 4 to 120 microns. A lower resolution of about 50 will be available from 2.5 to 120 microns for continuum observations. A single resolution of about 300 will be provided from 120 to 200 microns. A higher resolution at these long wavelengths would require unacceptably large optics. Figures 3 and 4 show the spectrometer sensitivity to continuum and line radiation.

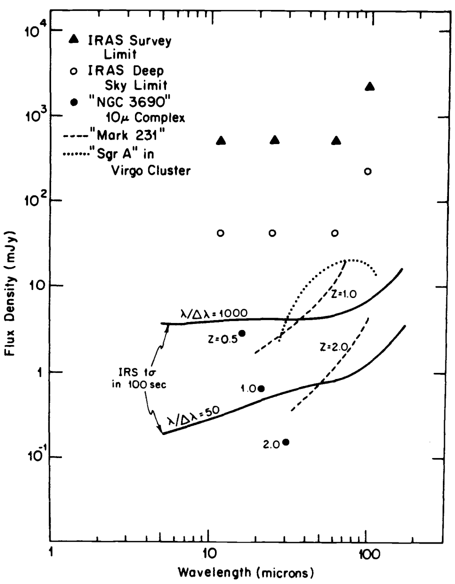

Figure 3. The sensitivity-to-continuum radiation of the low- and high-resolution modes of the spectometer is compared to IRAS. Data for several astronomical objects are scaled to greater distances are shown. The figure shows the spectrometer can study starburst galaxies (such as NGC 3690) to beyond z=1. A Galactic Center like our own can be studied to distances well beyond the Virgo Cluster.

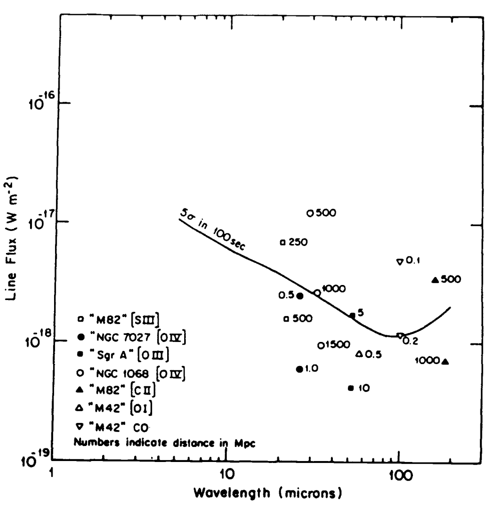

Figure 4. Sensitivity of high-resolution spectrometer for line detection. Expected fluxes for known sources scaled to larger distances are indicated for comparison.

We are in an early phase of the design of the software that will be required to control the instrument and support the research programs of the general investigators. Although realtime control and data analysis will not be possible except under the most unusual circumstances, it is important that turnaround times be as short as possible and that the system be "user friendly." To achieve these goals at a reasonable cost will require us to borrow heavily on the experience of other space missions and the knowledge and experience of the general community.

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